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Design and manufacturing of the Linko demountable fabric pavilion for the motorsport sector

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Abstract

This paper offers a detailed overview of the design and manufacturing aspects faced during the design and construction of the temporary pavilion for Linko Resources Ltd. The pavilion has been designed for the motorsport season 2015 and is based on bent aluminium profiles, designed to minimize the weight of the structures, and a double membranes skin realized through a PU coated Polyester fabric (waterproof layer) and a PVC coated polyester open mesh fabric (solar radiation control). The first section of the paper describes the requirements of the client, the architectural design and the structural design of the components. The second section presents the materials used, the connections and the optimization of the packaging in order to minimize the transportations volumes.

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Keywords: Motorsport, pavilion, MotoGP, coated fabric, temporary, demountable, aluminium

1. Introduction

Linko Resources Ltd is company based in London leader in the organization of events for the motorsport sector. Due to the growing demand of structures which balance the iconic architectural appeal with the increasing restrictions in terms of health and safety, time and space for the installation, transportation volume and budget,

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Linko Resources Ltd decided to develop a new generation of temporary structures for the events organized in conjunction with the motorsport races.

Maco Technology srl and the University of Nottingham have been appointed to design a new temporary pavilion to be connected to a standard 13m x 2.5m truck and optimized for the rapid installation through unexperienced workers according the current best practice [1] [2] and framework of European norms in terms of structural design and installation of temporary structures.

Fig. 1. View of the typical layout of the events. The reduced space available imposes an efficient installation procedure which minimizes the need of forklifts and other lifting devices.

2. The design of the pavilion on the basis of the client's brief

2.1. Requirements

The design of the pavilion was mainly based on the strict requirements stated in the client's brief. Linko Resources Ltd required a pavilion divided in two canopies to be attached along the two long sides of a 13m x 2.5m truck and able to cover the total overall area of 14.8m x 13.2m with a maximum high of 4.6m. Each component should weigh less than 25 kilograms in order to be easily handled by a single worker and the installation procedure should minimize works at heights and the need of ladders or lifting equipment. The structure, when disassembled, needs to be easily stored in the same truck which, however, is already loaded for 80% of its volume with the equipment and furniture for the events.

The current pavilions in used are generally focused on cost effective solutions, which generally result in and overall architectural appealing with is inadequate for the main brands and sponsors, or on fully automated pavilions equipped hydraulic actuators which requires budgets for the design, manufacturing and maintenance which are not accessible for minor categories/sponsors (Fig. 1). In addition, the growing number of races in the agenda with numerous events every week reduces the overall time for the installation/disassembly and transportation of the pavilions which makes less appealing the traditional concepts used in the last decade.

2.2. The design of the pavilion

The solution proposed to the client is based on two modular structures based on five arches obtained by bent aluminium profiles (Fig. 2). The arches are arranged in an orthogonal grid with an overall distance of 3.3m maintained constants through aluminium purlins arranged with a diagonal layout in order to prevent the lateral instability of the structure. The water proof layer is composed of a PU-coated polyester fabric with flexible keders along the boundaries in order to be installed through the four keder rails integrated in the aluminum arches. The required level of solar shading is obtained by means of an addition external layer of triangular sails made with a PVC-coated open mesh fabric. For specific applications the pavilion can be equipped with an internal false ceiling made with a lightweight grey/white nylon fabric.

The façade obtained from 8mm thick modular panels made of solid clear Polycarbonate. In order to minimized the number of components and the additional space required by traditional aluminium frames, the panels are connected to the aluminium façade by means of a special structural velcro by 3M^{TM}. The velcro is applied along the edges of the panels and on the structural aluminium profiles of the façade allowing an easy and rapid installation of the panels in respect of the expected forces (wind suction).

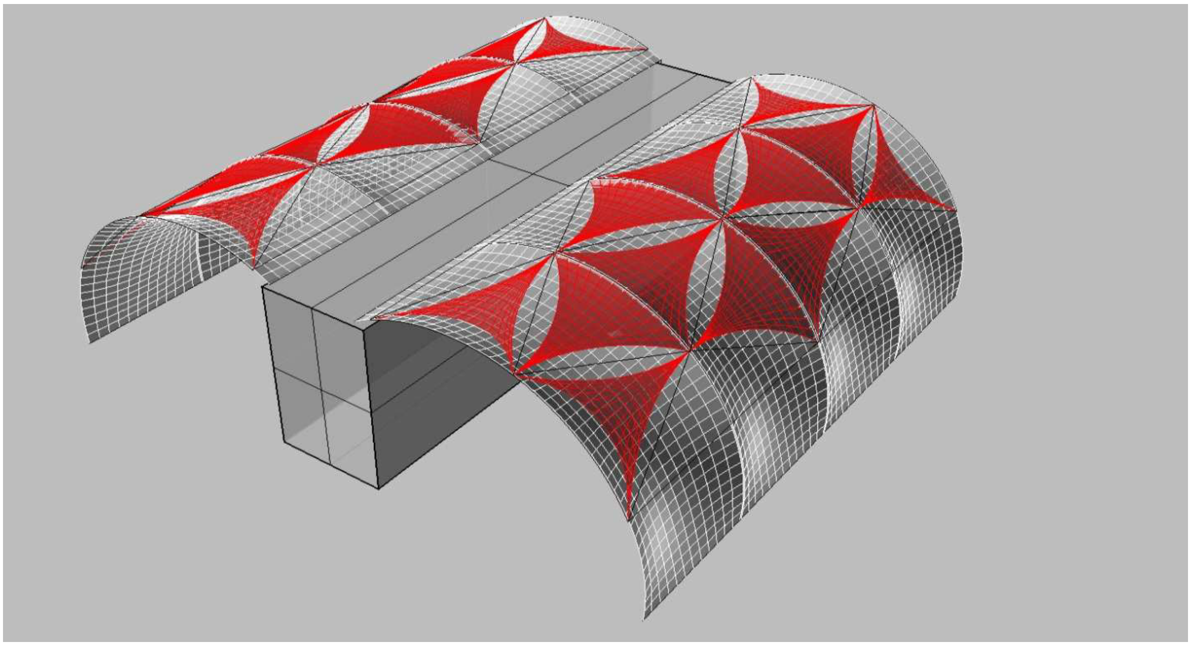

Fig. 2. The membrane envelope with the external shading layer highlighted in red.

3. The materials used

The materials adopted for the pavilion are the direct result of the progressive optimization of the structure and the several components. In terms of weight, each component should weigh less than 25 kg in order to be easily managed by a single worker. In addition, the lighter the structure, the quicker is the installation, with savings in terms of people and time required for the installation of each of the eighteen events scheduled for each season. For this reason the structural aches are made of extruded aluminium (6005A - Fig. 4) profiles which offer the additional advantage of low maintenance costs (the are profiles are anodized) and a cross section optimized for the integration of other components such as the cladding (external waterproof layer, external shading sails, internal false ceiling), the purlins, the LED lights etc.. The cross section is shown in Fig. 3 , the cross sectional area is $A_{strut} = 985\ mm^2$ and the second moments of area are $I_{strut,y} = 33.02 \cdot 10^4 mm^4$ and $I_{strut,x} = 98.96 \cdot 10^4 mm^4$.

The purlins are made of extruded aluminium (6005A) profiles with a circular hollow section with an external diameter of 50 mm and a wall thickness of 2 mm. The joints for the connections between the aluminium profiles, where there is the main concentration of stresses, are made of steel S235. The nominal values of the yield strength f_{yb} (235 N/mm^2) and the ultimate strength f_u (360 N/mm^2) for the structural steel has been obtained by using the data provided in table 3.1 of the Eurocode 3 Design of steel structures [3] which specifies the nominal values of yield strength f_{yb} and ultimate tensile strength f_u for hot rolled structural steel (Table 1).

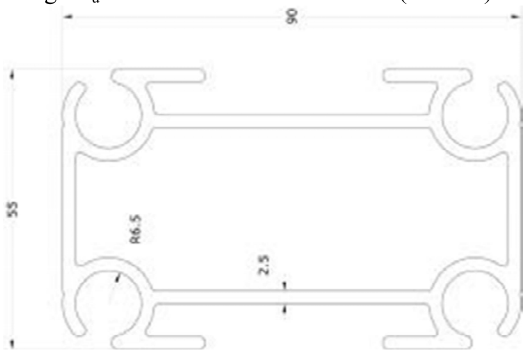

Fig. 3. Cross section of the aluminium profile used for the arches.

The coated fabric used for the lateral awnings is a polyester fabric coated with polyurethane and impregnated with a dirt deflecting finish able to resist to a water column of 5000mm. The coated fabric has a total weight of 270 gr/m^2, a tensile strength of 2300N/5cm and a tear resistance of 80 N/5cm. This solution provides an excellent aesthetical result with a reduced risk of wrinkles during the installation thanks to the flexibility of the fabric. In addition, the PU coating provides an elegant pearly finish with an excellent resistance to soiling and fungi which is crucial in case of dismantling in case of rain. The connections are stitched and taped in order to prevent the infiltration of water. The rigid façade is made of polycarbonate solid panels connected with a structural Velcro by 3M® which provides the required resistance to withstand wind suction and self-weigh minimizing the additional weight and volume required by traditional solutions based on rigid aluminium frames and mechanical connections.

Table 1. Mechanical properties of metal components used for the structural design.

Mechanical property	Value: Aluminium Components	Value: Steel Components (S235)
Modulus of elasticity	E= 70000 N/mm2	E= 210000 N/mm^2
Shear modulus	G=27000 N/mm^2	G=81000 N/mm^2
Poisson's Ration	ν=0.3	ν=0.3
Coefficient of linear thermal expansion	α=23×10-6 °K-1	α=12×10-6 °K-1
Unit mass	ρ=2700 kg/m^3	ρ=7850 kg/m^3

Alloy EN-AW	Product form	Temper	Thick-ness t mm 1) 3)	f_o 1)	f_u 1)	A 5) 2)	$f_{o,haz}$ 4)	$f_{u,haz}$ 4)	HAZ-factor 4)		BC 6)	n_p 7)
				N/mm²		%	N/mm²		$\rho_{o,haz}$	$\rho_{u,haz}$		
6005A	EP/O, ER/B	T6	$t \leq$ **5**	225	270	8	115	165	0,51	0,61	A	25
			$5 < t \leq 10$	215	260	8			0,53	0,63	A	24
			$10 < t \leq 25$	200	250	8			0,58	0,66	A	20
	EP/H, ET	T6	$t \leq 5$	**215**	**255**	8			0,53	0,65	A	26
			$5 < t \leq$ **10**	**200**	**250**	8			0,58	0,66	A	20

Key:
EP - Extruded profiles; EP/O - Extruded open profiles
EP/H - Extruded hollow profiles; ET - Extruded tube
ER/B - Extruded rod and bar; DT - Drawn tube

Note 1: Where values are quoted in **bold**, greater thicknesses and/or higher mechanical properties may be permitted in some forms, see ENs and prENs in 1.3.1.3.

Note 2: Where minimum elongation values are given in **bold**, higher minimum values may be given for some forms or thicknesses.

Note 3: Where an extruded product employs thicknesses across the thickness range given above, the highest value given may be used provided the manufacturer can support the value by an appropriate quality assurance certificate.

Fig. 4. Mechanical properties. Aluminium 6005A - T6 Extrusion according to the standard UNI EN 1999-1-1:2009 "Eurocode 9: Design of aluminium structures". Characteristic values of 0,2% proof strength f_o and ultimate tensile strength f_u (unwelded and for HAZ), min elongation A, reduction factors $\rho_{o,haz}$ and $\rho_{u,haz}$ in HAZ, buckling class and exponent np for wrought aluminium alloys - Extruded profiles, extruded tube, extruded rod/bar and drawn tube.

4. The structural design

4.1. Current building regulations

The structure is designed according to the current international standard UNI EN 13782:2015 "Temporary structure. Tents. Safety"[4] which replaces the previous standard UNI 10949:2001 "Safety of equipment for fairgrounds and amusement parks – Tents, temporary and/or itinerant fabric structure – Design, construction, installation and maintenance"[5].

The structural design of the aluminium frame is based on the international building codes UNI EN 1990:2006 "Eurocode 0: basis of structural design" , UNI EN 1991-1-4:2010 Eurocode 1: Actions on structures: Part 1-4: Wind actions, UNI EN 1999-1-1:2009 "Eurocode 9: Design of aluminium structures" [6] [7]. According to the UNI EN 13782:2015 "Temporary structure. Tents. Safety" seismic forces have not be considered because of the flexibility and the light weight of the tent.

4.2. Overall assumptions

The applied wind loads are based on the assumption of a structure correctly assembled and tensioned. It is recommended that the installation is supervised by an experienced engineer who should check the correspondence between the design assumptions and the actual installation of the structure. The structure has been designed for the warm season, in case of adverse weather conditions the designers prescribed the use of an adequate heating system in order to prevent accidental snow loads. Potential snow loads should be removed as soon as possible according to the health and safety procedures. The structure has been designed assuming no accidental loads due to water ponding. For this reason the structure should be assembled correctly and the membrane roof tensioned in order to allow the correct flow of the rainwater. The structural report specifies that potential anomalies should be reported to the engineer in charge of the structure. The stability of the structure is provided by a set of purlins and lateral bracings designed to maintain the constant spacing between the portals. In case of strong wind the structure should be closed in order to minimize the wind actions on the structure in line with the assumptions adopted for the structural design.

4.3. Expected loads on the structure

The pavilions have been designed for the anticipated loads estimated by means of Eurocode 1 “Actions on structures” [6] with a basic wind velocity vb = 27 m/s. Considering a peak velocity pressure q_p = 455.6 N/m^2 and an external pressure coefficient c_{pe} varying form 0.8 and -1.2, the external wind pressure on the roof is between 364.5 N/m^2 and -546.7 N/m^2.

The stress distribution in the membrane between the beams was also investigated with an additional FEA. The most relevant load case (ultimate limit state with wind as leading variable action) is shown in Fig. 5, where it is clearly visible that the anticipated maximum stress (5.5 kN/m) is less than the 9.2 kN/m given by the tensile strength of the PU-coated fabric (46 kN/m) divided by a safety factor of 5. In addition, the anticipated maximum stress is in line with the rupture test on the joints which showed a maximum stress at rupture of between 16.7 and 17.3 kN/m.

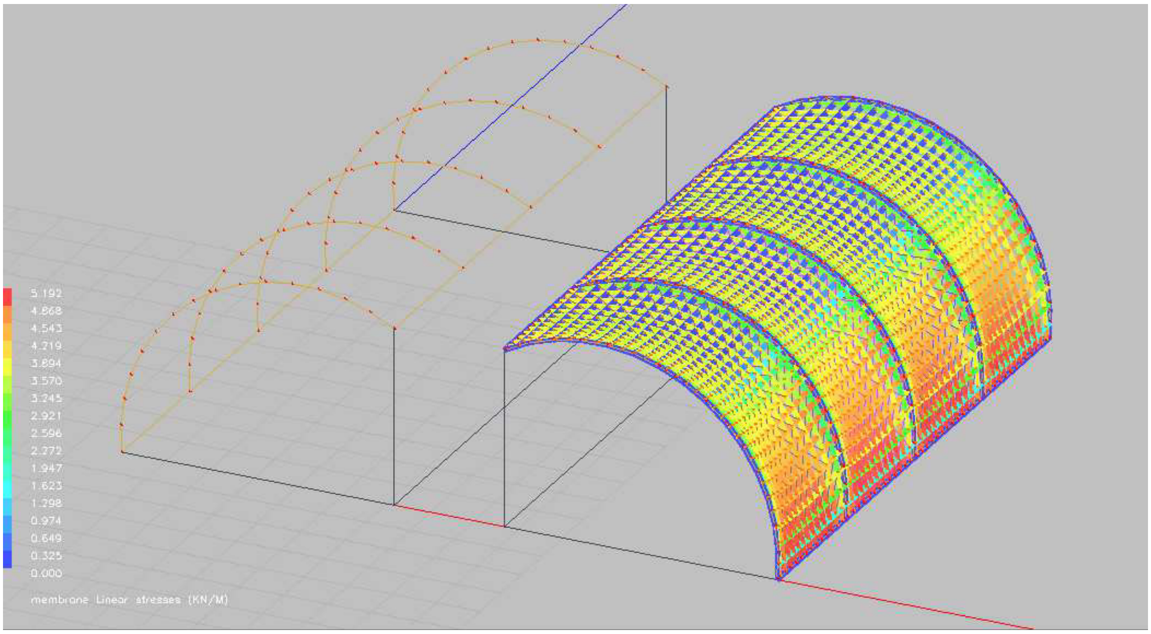

Fig. 5. Stress distribution in the roof membrane due to a wind speed equal to 27 m/s..

5. Assembly

The assembly procedure of the Linko demountable fabric pavilion is a key aspect which influenced the design of the structure since the early stages. The components are stored in the truck in a compact spaces in five large packages: the arches (disassembled in two components), the purlins, the frame for the façade, the polycarbonate panels for the façade and the bags of fabric for the canopy and the internal false ceiling.

The installation starts with the correct positioning of the truck which has direct implications on the correct alignment of the entire pavilion and the consequent successful installation. On one hand, the wrong vertical alignment can potentially create a conflict between the rigid façade and lateral surface of the truck; on the other hand an irregular ground needs to be compensated with leveling feet or other adjustable components.

Afterwards, the two parts of each arch are assembled and fixed to the truck in correspondence of the roof with a pinned joint that minimizes the action on the frame of the truck. The arches are stabilized and positioned at right distance by means of purlins arranged with a diamond layout designed to withstand the tension developed by the tensioned membrane roof and by the lateral wind load on the rigid façades. In order to accommodate inaccuracies due to the correct alignment of the ground and the truck, the purlins are equipped ball joints installed in correspondence of the two ends which allow the installation of straight elements on the curved surface and the compensation of misaligned components.

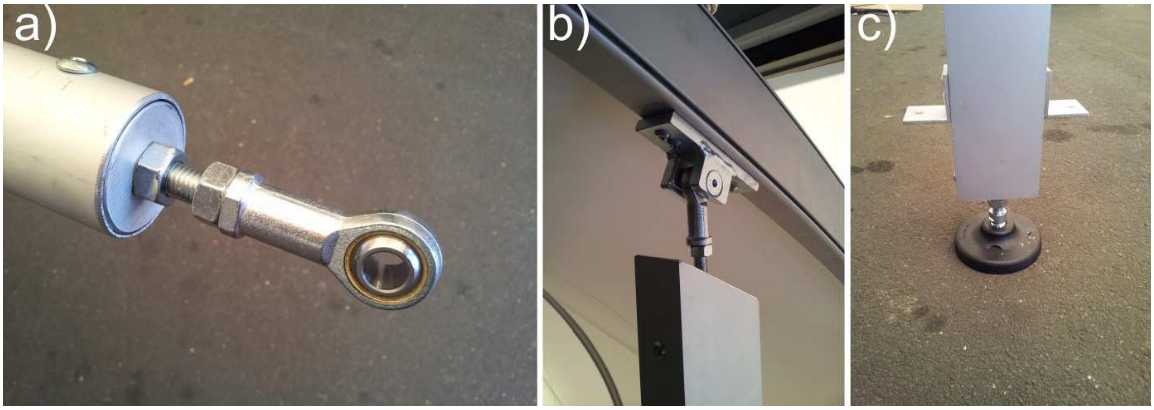

Fig. 6. (a) Detail of the ball joint assembled in correspondence of the two ends of each purlin; (b) Adjustable ball joint to align the aluminium frame of the façade; (c) Adjustable foot in correspondence of the arches and the vertical components of the façade.

Once the rigid frame is connected and fixed to the ground with ballasts (or plugs, anchors or fixings when possible) the membrane canopy is installed pulling the panel of fabric using the keder rails integrated in the extrude profiles. The fabric is connected to the roof by means of a keder profile applied to the U-shape profile attached to the roof of the truck in order to collect the water and distribute the applied loads. Finally, the membrane roof is tensioned by means of a rigid profile in correspondence of the lower part of the membrane roof. The external shading layer is applied using the fixings used for the purlins (Fig. 7). The internal false ceiling is installed using the internal keder rail integrated in the aluminium profiles.

The pavilion is completed by the rigid façade which is made by rigid panels in polycarbonate connected to the aluminium frame by means of a layer of 3M™ Dual Lock™ Reclosable Fasteners applied along the boundary of each panel. The solar radiation is controlled through the level of coverage of the graphic applied to the façade by means of a printed adhesive layer (Fig.8).

Fig. 7. View of the internal space with the external shading layer installed [9].

Fig. 8. Rigid façade made of rigid polycarbonate panels [9].

6. Conclusions

This paper described in detail the design and manufacturing aspects faced during the design and construction of the a temporary pavilion for Linko Resources Ltd. The pavilion has been developed for the Moto2 series in order to address the challenging requirements of the client in terms of overall price, installation procedure, transportation volume, weight and architectural appeal. The solution is based on bent aluminium profiles, designed to minimize the weight of the structures, and a double membranes skin realized through a PU coated Polyester fabric (waterproof layer) and a PVC coated polyester open mesh fabric (solar radiation control). The paper presents the requirement s of the client and describes the solutions adopted in the architectural and structural design of the components. The paper include the description of the material used and the results of the FEM analysis carried out.

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